A DEMONSTRATIONAL COLOR-PYRAMID

By E. B. TITCHENER

It is usual, in text-books and lecture courses, to represent the system of visual qualities by means of some tridimensional figure, sphere or double cone or hexahedron (double three-sided pyramid) or octahedron (double four-sided pyramid). I have long felt the need of a model of this figure,—a large model that should show, by actual pigment, the distribution of hue and tint and chroma in the visual system. In the course of a series of lectures on light and color, delivered during the summer of 1908 to a class of art-students, I was fortunate enough to secure the interest and cooperation of Mr. Louis Agassiz Fuertes, whose skill as a colorist requires no advertisement. For the immediate needs of the class, we constructed in cardboard a small water-colored model of the regular octahedral double pyramid; and this model did such good service that we judged it worth while to build a larger and more durable pyramid for regular use in class-room and laboratory.

The earliest colored *chart* with which I am acquainted is Lambert's single three-sided pyramid (J. H. Lambert, Beschreibung einer mit dem Calauschen Wachse ausgemalten Farbenpyramide, etc., Berlin, 1772). Aspects of the color-sphere are shown in colors by Runge and Steffens, in their Farbenkugel oder Construction der Verhältnisse aller Mischungen der Farben in der Natur, Hamburg, 1810. Many books contain colored plates that may, at a pinch, be useful to the lecturer: I mention, *e. g.*, the chromatic scale of tones printed as Plate v., and the chromatic circle of hues printed as Plate vi., in Chevreul's Principles of Harmony and Contrast of Colors, 3d ed., London, 1890. The Prang charts and Nendel's Farbenkreis should also be referred to; and the painted metal plate of equated Urfarben and grey, contained in Hegg's Die invariablen aequivalenten Oelpigmente zur Farbenperimetrie, is indispensable. Since, however, the system of visual qualities is in fact tridimensional, colored charts can never be wholly satisfactory; they give, at the best, a series of typical aspects which must be imaginatively combined by the spectator.

In this connection I am tempted to remark that the two-dimensional representation of a tridimensional system in Ross' Theory of Pure Design (1907) has, in my opinion, brought the author into serious conflict with psychological fact. Ross admits three variables in the color impression, value, color and intensity (tint, hue and chroma). His classificatory diagram 4 (facing p. 140) is, however, essentially two-dimensional, though it can be translated into a color pyramid if we ignore the extreme length of the lines R-Y and B-R (due apparently to the existence of the color-names orange and violet) and the

extreme lowering of V (due in part, perhaps, to the exigencies of the diagram itself, and in part to the darkness of V in the ordinary dispersion spectrum: see p. 139). No one can quarrel in principle with empirical rules of procedure; but one may object to the distortion of theory, *i. e.*, in this case, of psychological observation.[1] There seems, indeed, to be not even an empirical reason for the lowering of V; such, at any rate, was Mr. Fuertes' experience in the painting of our model.

A *model* of the double cone, 12 in. from pole to pole and 8 in. in diameter at the base, was put upon the market ($4.00) by E. G. Willyoung & Co. in 1896. I am informed that the model showed no color, but simply copied, in black and white, Fig. 88 of Scripture's Thinking, Feeling, Doing, 1895, p. 158 (*cf.*, however, The New Psychology, 1897, pp. 345 ff., Figg. 87, 88). Two models, a "Farben-Oktaeder, zerlegbar in die acht Oktanten" and a "Farben-Doppeltetraeder", are listed by Höfler and Witasek in their Psychologische Schulversuche mit Angabe der Apparate, Leipzig, 1900, p. 4 and 1903, p. 5. The former "zeigt am Umfange des horizontalen Achsenschnittes die gesättigten Farbentöne (Grund- und Mischfarben), an den Spitzen der vertikalen Achsen Weiss und Schwarz, an den Innenschnitten die Anteile verschiedener Grau an den nicht gesättigten Farben". Details of construction are promised, in both editions, for a forthcoming number of the *Zeitschrift f. Psychol.*, but the article has not appeared. The cuts suggest small models of painted wood or plaster; the price (Kr. 10.60 and Kr. 4 respectively: say $2.25 and $0.85) seems to indicate that the colors and greys are only roughly represented.

The octahedral double pyramid, which embodies the fundamental facts of the 'antagonistic' theory of visual sensation, was figured in 1897 by Höfler and Ebbinghaus. Höfler's pyramid has the form of a regular octahedron (*Psychologie*, 1897, p. 113, Fig. 12; *Grundlehren der Psychologie*, 1897, p. 35, Fig. 9). Ebbinghaus brings the figure into better accordance with psychological requirement by tilting the Y-angle of the base up towards W, and by rounding off the poles and base-angles (*Grundzüge d. Psychol.*, erster Halbband, 1897, p. 184, Fig. 15; or i., 1905, p. 199, Fig. 18). We decided to tilt the base of our model, partly because the relative displacement of Y and its antagonistic B helps the student to grasp the meaning of 'tint' as applied to color, and partly because the painting of the model in this form is much easier; theory and practice are, so far, in agreement. We did not, however, round off the poles and the corners of the base. There would have been no appreciable gain, that we could see, on the technical side; the model would have been more expensive; and there would have been incorporated in it a point of exposition which, as experience shows, may more safely be postponed. Our own pyramid, then, as painted by Mr. Fuertes, finally

[1] *Cf.* A. H. Munsell: A Color Notation, 1905, 12. "Two dimensions fail to describe a color. Much of the popular misunderstanding of color is caused by ignorance of these three dimensions or by an attempt to make two dimensions do the work of three." Munsell uses hue, value and chroma for the three qualitative attributes that I term hue, tint and chroma.

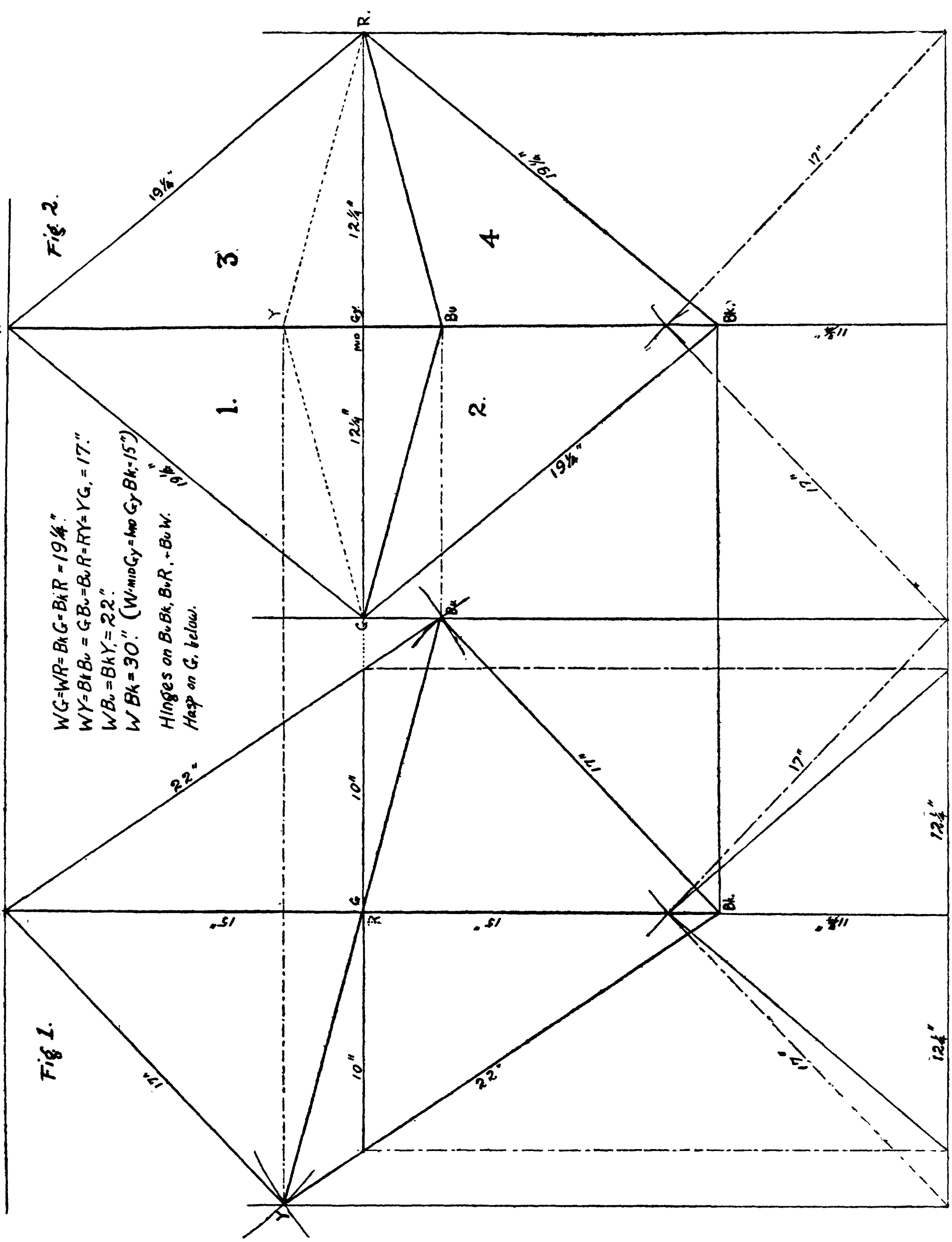
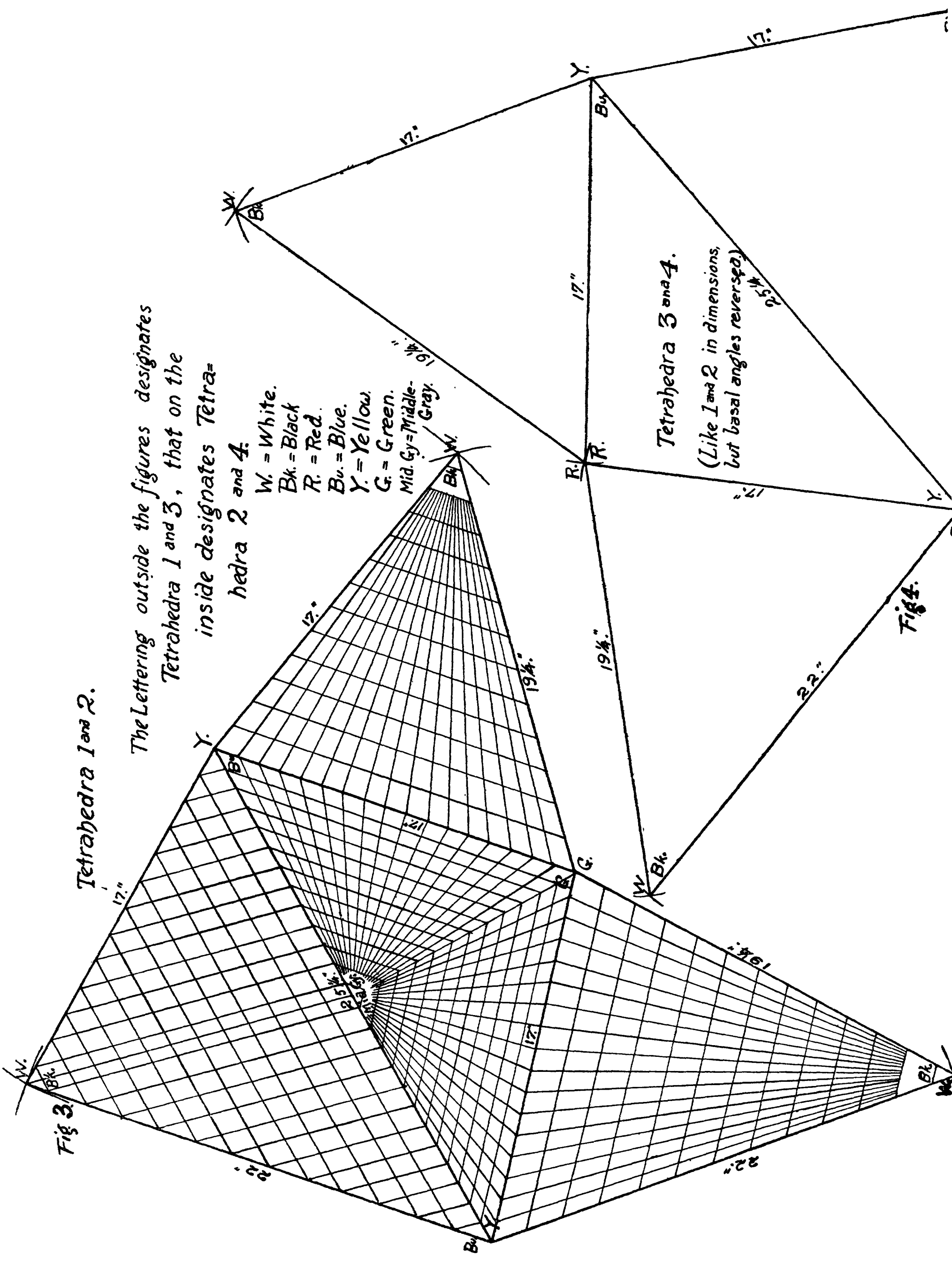


Fig. 2.
Fig. 1.
WG=WR=BkG=BkR=19¼"
WY=BkBu=GBu=BuR=RY=YG,=17"
WBu=BkY,=22"
W Bk=30" (W-MID Gy=MID Gy Bk=15")
Hinges on BuBk, BuR, + BuW.
Hasp on G, below.
W
R.
Y
MID Gy.
Bu
Bk.
G
1.
2.
3
4
19¼"
12¼"
17"
22"
10"
15"


Tetrahedra 1 and 2.
The Lettering outside the figures designates Tetrahedra 1 and 3, that on the inside designates Tetrahedra 2 and 4.
W. = White.
Bk. = Black
R. = Red.
Bu. = Blue.
Y. = Yellow
G. = Green.
Mid. Gy = Middle-Gray.
Tetrahedra 3 and 4.
(Like 1 and 2 in dimensions, but basal angles reversed.)
Fig 3.
Fig 4.

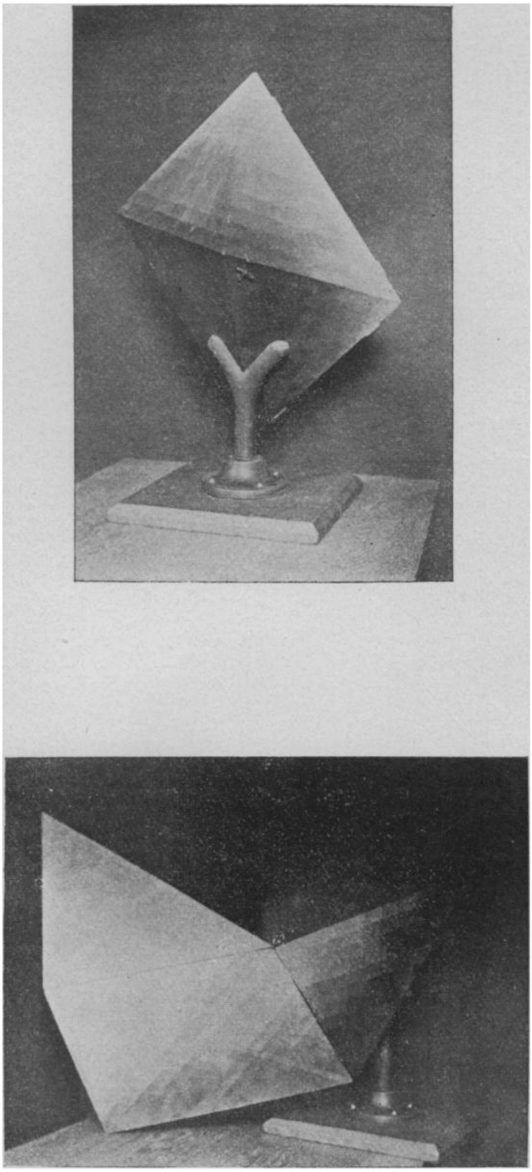


PLATE I

assumed the form shown in the accompanying photographs. I append details of its manufacture, in the hope that they may be of value to other psychologists in lecturing to large undergraduate classes: the model saves at least a full hour of classroom time, and a good deal of unnecessary puzzling on the part of the student. In case the cost still appears excessive, I suggest that the figure may easily be constructed (from the plans here given) of heavy white cardboard, with white cloth hinges, and that a very moderate degree of skill in watercoloring will suffice to produce a serviceable model.

To construct the unit-tetrahedra, lay off the triangle BuYG: BuY = 25.25, YG = 17, GBu = 17 in. On BuY as a base, lay off BuW = 22 and YW = 17 in. On YG as a base, lay off YW = 17 and GW = 19.25 in. Finally, on GBu as a base, lay off GW = 19.25 and WBu = 22 in. These four triangles placed together will make tetrahedra 1 and 2; with the same measurements, but with the angles reversed, they will make tetrahedra 3 and 4. The four tetrahedra, fitted together as in Figg. 1 and 2, form the double pyramid required.

The material used is specially selected, trebly seasoned 'state' whitewood, ⅝-in. thick. Attached firmly to the angle GBk is a forked walnut standard which, seated at the base in a strong swivel socket, allows the model to be revolved about a vertical axis. The standard is fixed to a cast-iron base, 16 by 16 by 1.5 in. Two small pin-hinges, set as closely as possible to the surfaces, are placed on the edge BuBk; two others on BuR; and two others on BuW. These, while holding the model together in one piece, allow of its being opened to show a vertical section through W, Bu, Y, Bk and to show a peripheral section through R, Y, G, Bu and middle grey. A single pin-hasp, hooking from G slightly below the periphery and across the edge BkG, locks the entire model.

To ensure uniformity of gradation in the coloring, the entire surface of all the tetrahedra was plotted, as shown in Fig. 3, on a unit of one inch, taken on the sides of the base triangles and thence projected upon the remaining three faces. On the surfaces of section Bk, Bu, W, Y, the figures thus formed are rhomboids which decrease by twos in the direction from base to apex; on all the other surfaces the figures are rhomboids which show the same number (17) in all rows. The plotting was done with a hard pencil-point on the raw wood.

To prepare for the coloring, the whole of the upper pyramid and the upper half of the lower pyramid were first painted with a good coat of flake white mixed in pure boiled linseed oil. The lower part of the lower pyramid was simply given a thorough oiling, the white being brushed out evenly along the line of junction. After this treatment, the model was allowed to stand for three weeks. It was then entirely dry, and no color could 'sink' after application.

The colors used were J. H. Hatfield's hand-ground oil colors, and the palette was selected by Mr. Hatfield with special reference to our requirement of pigments that should produce purest hues of maximal chroma, and should not interact chemically or change on long exposure to light. The paints selected were: zinc white, flake white, ivory black, vert emeraude, aureolin yellow, light cadmium yellow, cadmium orange, orange vermilion, fast deep vermilion, rose madder, cobalt violet, ultra-marine blue, American cobalt blue and French cobalt blue. These colors, lightened with white only, make it possible to render the outer surfaces at high chroma, even at very light tints; they also furnish a high chroma for the lower pyramid. It was

found that the blues required a good deal of lifting even to reach the 'pure blue' level.—The addition to the above list of a tube of burnt sienna simplifies the complicated mixing for dark yellows, which tend strongly to fall over towards green or red.

The first step of the painting was to work out carefully the colorless series along the BkW axis. This was laid off in 25 stages, with pure W and pure Bk at the poles, and 23 graded neutrals between. Enough of the neutrals was mixed to modify all the chromas of Bu and Y, between the limits of black and white, on the vertical section, and enough of middle grey to modify all the hues of the peripheral section.

In painting the outside faces, the periphery was first established, all four tetrahedra being thus far carried on together. The start was made at Y with light cadmium, which was taken to express the maximal chroma of yellow. This was worked, step by step, into cadmium orange, pure, and thence through orange vermilion into fast deep vermilion, which expresses a nearly perfect red at maximal chroma. The f. d. vermilion was then worked through rose madder (with white) and cobalt violet to cobalt blue (with white) which forms the note at Bu. This mixture gives a very good middle blue, which works evenly into a green-blue with the addition of vert emeraude, which in turn is nearly perfect (needing only a little white) for blue-green. If the white is now gradually replaced by light cadmium, an excellent high-chroma green is obtained for G; and serial reduction of the green and increase of the light cadmium gives the GY line. These colors form the first row on both planes of all edges of the periphery.

The faces towards W are produced simply by serial addition of white to the notes already established. Those towards Bk offer a much more serious problem; the mechanical mixture of black with the hues of the periphery does not result in the required gradations. Red must be worked down through rose madder *plus* orange vermilion, with black added where necessary. Blue, as the white component of Bu is diminished, becomes darker in tint without loss of chroma to a point nearly (if not quite) half-way towards Bk. Vert emeraude is nearly as dark, and must be treated in nearly the same way. The green at G can be developed down a few steps by reduction of the light cadmium; then this must be replaced by aureolin *plus* cadmium orange; and then the black increment must begin. The series downward from G-Y is the most difficult and complicated of all, and must in large measure be left to the skill and eye of the painter; the changes, as the different colors are employed, are very instable, and the proportions must be sought empirically. Especial care must be taken with the colors between green-yellow and Y, if they are to be kept clear, and not to lean over towards red or green. A little burnt sienna will tend, as was said above, to warm and clear the difficult series of ambers and browns between Y and Bk; it also works well into the dark oranges between YBk and RBk.

The painting of the sections (both surfaces of which were covered) was comparatively easy. On the vertical section, the chroma of the peripheral blues and yellows was decreased by adding the serial increment of the neutral found at the middle line in the same row. On the peripheral section, very little besides middle grey was required to neutralize all the hues; when the grey component becomes predominant, the color lies so near the horizontal plane that middle grey may be used without appreciable error. To have laid other sections through the model would have impaired its stability, and would have added considerably to its cost. On the other hand, there is no difficulty, when once the faces described have been painted, in coloring

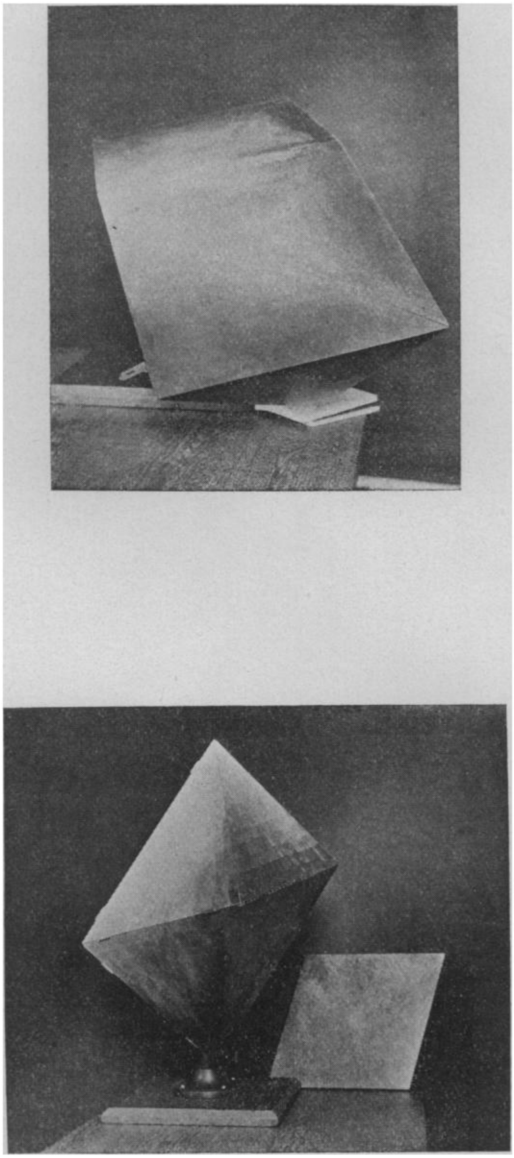


PLATE II

other surfaces that represent planes of section in any direction. We have worked out only one of these: the horizontal plane that passes through R, G, and middle grey, and therefore also through a high blue and a low yellow. A separate rhombus of wood was made to the required dimensions; the hues were laid off along the periphery by reference to the painted pyramid; and the surface, showing all hues in all chromas at the tint of middle grey, was treated in the same way as those of the peripheral section. It is probably unnecessary to prepare more of these sectional surfaces; students who have followed the construction of the pyramid on the blackboard, and have been led to the complete model by way of the Hegg plate and the separate rhombus, find no special difficulty in following imaginary lines and covering imaginary planes within the color system.

The price of the wooden model was $26, and of the iron base, $3; the cost of the pigments, brushes, etc., a little over $7. Given the necessary skill in painting, the model can therefore be reproduced for $37.

Explanation of Plates

Plate I. Color-pyramid, closed, seen from back. Shows pin-hasp at G, and forked support.

Color pyramid, open. Shows vertical section.

Plate II. Color pyramid, open. Shows peripheral section.

Color pyramid, closed, seen from front, the R-angle facing observer. Separate rhombus (horizontal section) at side.